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A Wide Beam Printed Quadrifilar Helix based Circularly Polarised Radiating Element for Electronically Steered Antenna

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ABSTRACT

Wide beam and low axial ratio performance of printed quadrifilar antennas result in very attractive circularly polarised radiating element for wide scanned Electronically Steered Antenna. A compact printed quadrifilar Helix antenna (PQHA) has been designed and realised at S-Band frequency. Simulation and optimisation of designed antenna has been performed using ANSYS's high frequency structure simulation (HFSS) software for its impedance, axial ratio (AR) performance and radiation characteristics. The developed circularly polarised antenna has 3-dB beam width of 130° and peak gain of 3.4dBic at 2.6 GHz. The developed antenna shows excellent AR performance over the frequency band as well as over the radiated beam. Half power axial ratio bandwidth of developed antenna is 27.4% (2.2 GHz - 2.9 GHz) while the impedance bandwidth is 32% (2.1 GHz - 2.9 GHz). Design has been validated through measured results. Designed wide band PQHA can be used as radiating element for electronically steered antenna for large beam steering application.

Keywrods: Axial ratio; Circular polarisation; Feed; Helix; Printed quadrifilar antenna; VSWR; Wideband

1. INTRODUCTION

Wide beam steering of the electronically steered antenna (ESA) demands wide beam radiating element for low scanning loss. For circularly polarised (CP) ESA system, the radiating elements are characterised by its axial ratio performance over the frequency as well as over the radiated beam. Printed quadrifilar helix antennas, having excellent CP performance over the frequency band as well as over the radiated beam, are best suited as radiating element for electronically steered antenna[1-3].

Wide beam and large bandwidth are the main advantages of the printed quadrifilar antenna over other configurations of circularly polarised radiating element. This property of PQHA makes them suitable for use in applications where wide beam coverage or hemispherical type of coverage is required. Beam width of the radiating elements of phased array antenna decides the beam scanning loss. The scanning loss in Electronically Steered Antenna is equal to reduction of power level in the radiation pattern from its bore-sight level at the steered angle i.e. if the antenna has 3-dB beam width of 130° then upon beam steering of ±65° from bore-sight the maximum scan loss would be 3dB. For airborne applications, where the platform movement demands wide beam steering, this parameter becomes even more important. Printed quadrifilar helix antenna, having 3-dB beam width of 130° (axial ratio < 3dB over the beam), is most suitable radiating element for circularly polarised Electronically Steered Antenna for ±65° beam steering. Due to its wide beam, PQHA can also be used as radiating element for wide coverage S-Band portable hand held terminal.

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Radiation from the quadrifilar helix antenna is circularly polarised and has same sense of polarisation throughout the entire radiation sphere. Gain and coverage of the antenna can be optimised by selecting the appropriate number of turns of he Helix.

PQHA is made up of four parallel metallic strip lines, etched on a dielectric substrate which is wrapped around a dielectric cylinder. Four lines are fed through sequentially quadrature phase feeding network. By selecting the appropriate diameter of helix, a wide range of radiation pattern shapes can be obtained.

Quadrifilar helical antenna was firstly introduced by Kilgus[4-6]. Besides excellent CP performance, printed quadrifilar antenna also has number of other advantages such as compact structure, low cost, wide coverage etc.[7-8].

Several techniques have been reported by authors to increase the impedance and axial ratio performance of printed quadrifilar helix antenna[9-12]. Louvigne & Sharaiha[9] discusses the bandwidth enhancement technique of printed quadrifilar antenna and achieves bandwidth of 7% at L-Band frequency. Sainati[10], *et al.* reported quadrifilar antenna with dual band operation at S-Band frequency with bandwidth of 7.7% at each band. Lamensdorf & Smolinski[11] has developed a dual band printed quadrifilar antenna with bandwidth of 6% at L-Band frequency. Chow[12], *et al.* describes a quadrifilar helix antenna having wide impedance bandwidth but the AR bandwidth is very small. Design and analysis of compact PQHA with enhanced CP bandwidth has been discussed by Louvigne & Rabemanantsoa[13-14], *et al.* In this, author uses tapered printed quadrifilar antenna configuration for size reduction as well as multi band operation.

Wang & Chung[15] developed a wide beam printed quadrifilar antenna at L-Band frequency. The designed antenna has impedance bandwidth and AR bandwidth less than 2%. Axial mode folded printed quadrifilar Helical antenna (FPQHA) has been used for large impedance bandwidth (~30%)[16]. Ibambe[17], *et al.* used the meandering line techniques to reduce the height of PQHA and claims to reduce the size of antenna by 33% along with its enhanced efficiency. Byun[18], *et al.* realised a dual band compact PQHA using stepped arms. Variable widths of helix arms with different pitches have been utilised to enhance the impedance bandwidth[19]. In this paper, author has achieved 12% impedance bandwidth with good radiation characteristics and axial ratio < 3dB.

Roy[20], *et al.* realised a sectoral conformal circular patch antenna with shorted wall to minimise the overall size and beam broadening. The paper also includes the study of antenna's radiation performance mounted on aerial platform. Dielectric loaded spiral-folded PQHA has been used for effective size reduction of antenna by Han[21], *et al.* In all of the above papers authors have developed antennas with wide impedance and axial ratio bandwidth but they are not suitable as radiating element for ESA due to their smaller beam width and limited axial ratio bandwidth performance.

In present paper, a wide beam, wide band printed quadrifilar antenna at S-Band frequency has been proposed. Developed PQHA shows excellent impedance and AR bandwidth performance along with wide beam width. The developed antenna has impedance and AR bandwidth of 32% and 27.4% respectively. Achieved beam width of the antenna is 130°.

2. ANTENNA STRUCTURE AND DESIGN

Helix antennas are generally known for generating circular polarisation over wide band of frequency. Quadrifilar Helix Antenna (QHA) consists of four helical radiating elements, located at equal distance on the circumference of low loss dielectric cylinder and excited with RF signal of equal amplitude and quadrature phase through a phasing network. The phasing networks provide 0°, 90°, 180°, and 270° phases to helical elements and also improves impedance matching over wide frequency band.

A helix antenna consists of two types of radiating elements namely dipole and the loop antenna. The helix antenna's polarisation is decided by length of dipole and the diameter of loop antenna. By proper selection of length of dipole and diameter of loop, we can obtain circular polarisation. In quadrifilar helix antenna, the feeding network should have equal amplitude at each helix. The phases at each helix should be in phase quadrature with respect to adjacent helix. By properly maintaining the amplitudes and phases at ports of feeding network, wide band performance of the antenna can be obtained.

PQHA consists of four helical radiating elements etched on thin dielectric substrate and wrapped around a low loss dielectric cylinder. Dielectric substrates on which the helixes are printed are mainly characterised by its dielectric constant, loss tangent and thickness. A thicker substrate for printed quadrifilar antenna can improve the impedance bandwidth and mechanical rigidness but at the same time it increases the weight of antenna. Other disadvantages include dielectric loss, surface wave loss and extraneous radiation from the feeding probe. For printing of feeding network a thicker substrate, 50 mils Roger's RO 3010 (ε_r = 10.2, tanδ = 0.0035) is used. High dielectric constant confines the fields within the circuit. For good radiation characteristics, the dielectric substrate for printing of radiating element should be thin, having low dielectric constant and low loss tangent. Keeping all of the above points in mind, 5 mils Roger's 5880 substrate (ε_r = 2.2, tanδ = 0.0009) has been selected for printing of helix structure.

For axial mode radiation, length and width of printed quadrifilar helix strip has been calculated theoretically and optimised through EM simulation software. Spacing between two lines has been optimised for wide beam coverage with low axial ratio. The folding diameter and pitch angle has been selected to obtain wide band axial ratio performance. The antenna has been folded over a hollow dielectric cylinder with diameter of 18mm. SMA connector has been used as input in the present design.

Sketch of printed quadrifilar antenna with notations is given in Fig. 1.

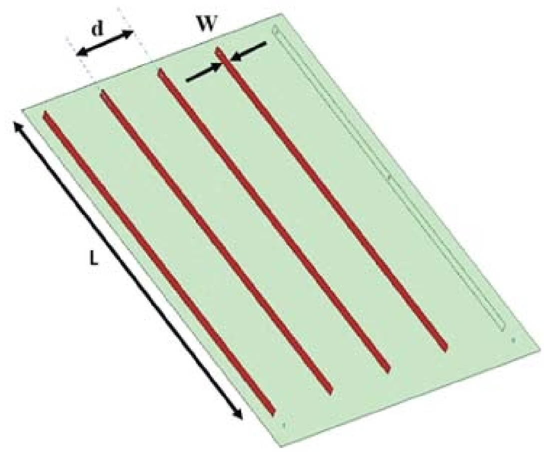
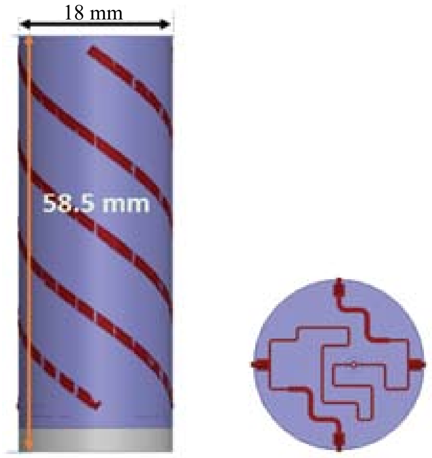


Figure 1. Sketch of a printed quadrifilar helix PCB with notations.

CAD model of the deigned PQHA along with its feeding network is shown in Fig. 2. A 1:4 amplitude matched and phase quadrature compact feeding network has been selected to feed the four helical radiating elements. The length of the feeding lines has been selected in such a manner that the phases at each ports are 0°, 90°, 180° and 270° with respect to input port. Simulation and optimisation of designed antenna has been carried out in ANSYS's HFSS EM simulation software. Optimised dimensions of the designed antenna are provided in Table 1. Simulated results shows that the



(a) (b)

Figure 2. CAD model of (a) Printed Helix (b) Feed network.

Table 1. Optimised dimensions of designed PQHA

Parameters	Value
Substrate for quadrifilar helix	5 mils Rogers 5880
Substrate for feeding network	50 mils Rogers RO 3010
Radome material	1.3 mm thick Teflon
Length of printed strip (L)	73.5 mm
Width of printed strip (W)	0.8 mm
Distance between two lines (d)	14.1 mm
Folding diameter	18.0 mm
Pitch angle	53°

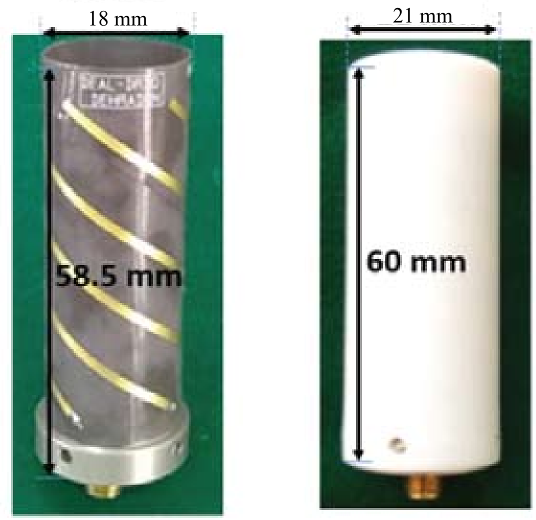
impedance bandwidth and AR bandwidth of the designed antenna is better than 0.75 GHz. Simulated peak gain and beam width of the designed antenna at 2.6 GHz is 3.8 dBic and 130° (for AR less than 3dB over the beam), respectively.

3. EXPERIMENTAL RESULTS

Designed quadrifilar helix antenna and feeding network has been developed. A hollow dielectric cylinder is fabricated to support the PQHA. Developed antenna has been soldered with the feeding circuit. Photograph of fabricated PQHA with and without radome is shown in Fig. 3. After integration, the diameter of antenna with radome is 21mm and the height is 60mm.

Anritsu's vector network analyser (VNA) has been used for VSWR measurement of the developed antenna. Comparison of simulated and measured VSWR of the antenna is illustrated in Fig. 4. Graph shows excellent agreement between simulated and measured VSWR values. VSWR 2:1 has been achieved over 2.1 GHz to 2.9 GHz. Test setup for measurement of radiation characteristics of developed antenna is presented in Fig. 5. The plane of radiation of the designed PQHA is in axial direction. The antenna is placed in anechoic chamber in such a manner that the top of the antenna is pointed towards the transmitting antenna so that polarisation of transmitting and receiving antenna matches to each other.

Simulated and measured axial ratio over the frequency band is plotted in Fig. 6. Measured axial ratio is less than 3dB over 2.2 GHz to 2.9 GHz and it closely follows the simulation results.



(a) (b)

Figure 3. Developed (a) PQHA and (b) antenna with radomes.

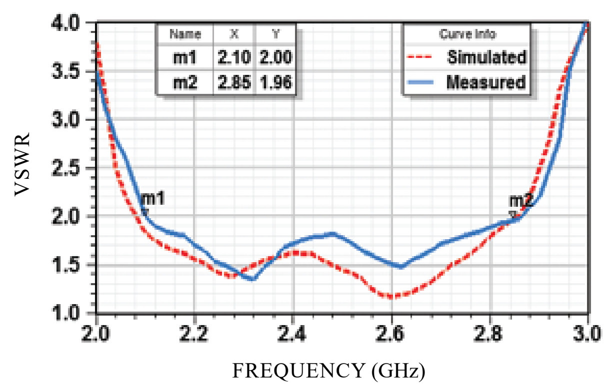


Figure 4. Measured Vs simulated VSWR of developed PQHA.

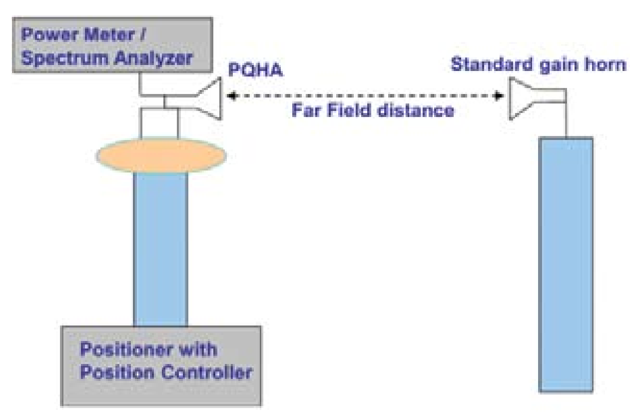


Figure 5. Test setup for pattern measurement of antenna.

Axial ratio plot of designed PQHA over the beam is given in Fig. 7. The graph reveals that the AR performance of the developed antenna over 130° beamwidth is less than 3dB, making it suitable for beam steering of ±65°. Measured results of the designed PQHA are in-line with the simulated results over the desired frequency band.

Measured Vs simulated RHCP radiation pattern of designed antenna is given in Fig. 8.

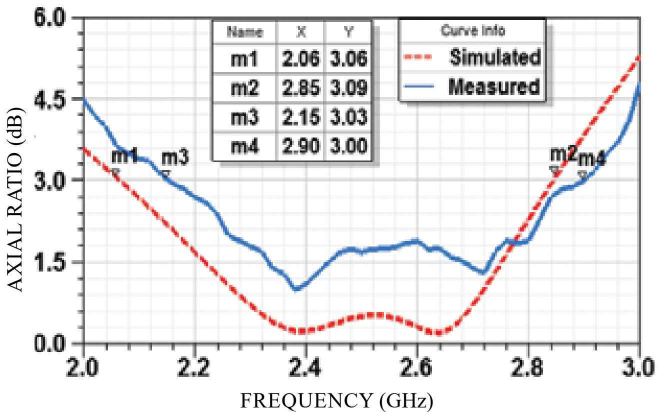


Figure 6. Measured Vs simulated axial ratio over the frequency band.

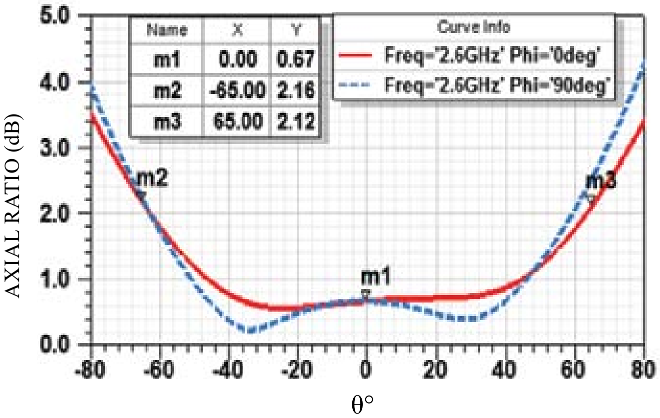


Figure 7. Measured axial ratio over the radiated beam at 2.6 GHz.

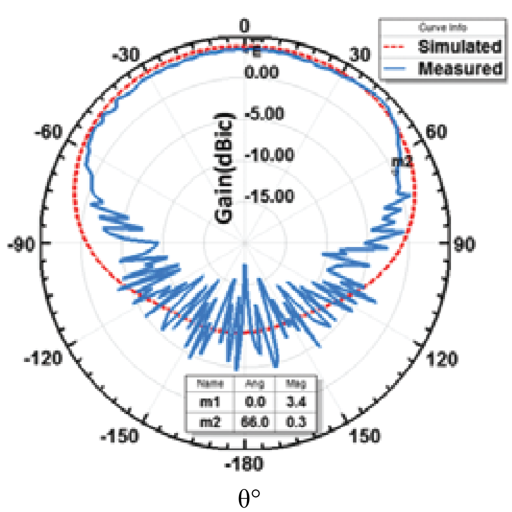


Figure 8. Measured Vs simulated RHCP radiation pattern at 2.6 GHz.

Radiation pattern measurement of developed antenna shows that measured gain, beamwidth and axial ratio (over the beam and over the frequency band of operation) are in excellent agreement with their simulated results. Measured axial ratio over the beam (±65°) is < 3dB and measured peak gain is 3.4dBic @ 2.6 GHz. Measured 3-dB beamwidth is more than 130°.

4. CONCLUSION

A wide beam and wide band compact printed quadrifilar helix antenna has been designed, simulated and developed. Measured impedance bandwidth and 3-dB axial ratio bandwidth are 32% (2.1 GHz - 2.9 GHz) and 27.4% (2.2 GHz - 2.9 GHz) respectively. Peak gain of the developed antenna is 3.4dBic at 2.6 GHz. The antenna shows excellent axial ratio performance over the frequency band as well as the over the radiated beam. The developed antenna has 3-dB beam width of 130° with axial ratio less than 3dB making it suitable as radiating element for ±65° beam steering of ESA with scan loss of 3dB. Designed antenna is potentially suitable candidate as radiating element for wide scan ESA.

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His contribution in the paper is design, simulation and evaluation of antenna.

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His contribution in the paper includes the simulation and evaluation of antenna.

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